Under identical geological conditions one may furthermore assume that the diameters of the developing cavities d_H and the diameters of the compression zones d_V in case of two equivalent detonations of q_1 and q_2 behave like:

$$\frac{d_{H_1}}{d_{H_2}} = \frac{d_{V_1}}{d_{V_2}} = \left(\frac{q_1}{q_2}\right)^{\frac{1}{3.4}} \qquad (2.29)$$

As criterion for a nuclear weapon detonation with a completely internal effect we can take the minimum necessary detonation depth or "line of least resistance" for tufa as follows:

$$-H_{min} = 120 \cdot q^{\frac{1}{3.4}} \quad \text{m} \qquad (2.30)$$

Up to detonation depths of:

$$-H_0 \approx 95 \cdot q^{\frac{1}{3.4}} \quad \text{m} \qquad (2.31)$$

We can expect significant destruction along the earth's surface.

Review Questions

2.1. How can we explain the fact that the blast wave front is separated from the isothermal sphere during the fireball's second development stage?

2.2. How can we explain the origin of the second temperature maximum in the fireball's development.

2.3. How do the detonation intensity and detonation altitude influence the size and shape of the fireball?

2.4. According to what rough formula can we draw conclusions regarding the detonation intensity from the illumination time of the fireball?

2.5. Explain the process of detonation cloud formation.

2.6. What are the factors that essentially determine or influence the dimensions, climbing heights, and shapes of detonation clouds?

2.7. Why does the character of radioactive terrain contamination essentially depend on the degree to which the stem and the condensation clouds are merged?

2.8. What does the heavy influence of the tropopause on the maximum climbing height of the detonation cloud result from?

2.9. Under what conditions will a crater be formed after nuclear weapon detonations?

2.10. List and explain the most essential crater elements following ground and underground bursts.

At H_D = 0 m we speak of a contact detonation where the fireball initially is completely hemispherical but then it immediately extraordinarily deforms. The detonation altitude, at which the fireball from a nuclear weapon detonation of a certain intensity touches the ground, cannot simply be determined by comparison with the particular maximum fireball radius.

This is due to the fact that the fireball reaches its maximum extent only during a certain period of time, that it moves upward at the same time while it spreads out, and that it is furthermore flattened out along its underside by the blast wave which is reflected along the earth's surface. It is generally assumed that no contact takes place between the fireball and the earth's surface with a high degree of certainty if the detonation altitude at least corresponds to the size of the fireball's radius at the time of the second temperature maximum ($t(T_{max}) = 0.065 \cdot q^{2/3}$ s). According to Schrader[4] the following empirical formula then applies to the dependence between the fireball's radius according to Formula 2.5 when $t = t(T_{max})$ and the detonation intensity q:

$$\frac{R_1}{R_2} = \left(\frac{q_1}{q_2}\right)^{2/3} \qquad (2.6)$$

Further considerations regarding the fireball can be found in Section 4.1 in connection with the treatment of the general characteristic of the destruction factor which we call light radiation.

2.1.2. Detonation Cloud

A cloud characteristic of the particular detonation type is formed a few minutes after a nuclear weapon detonation.

The radioactive detonation cloud has the shape of a mushroom during detonations in which the fireball at least partly reaches the atmosphere. It consists of the detonation cloud as such (the condensation cloud) and the stem which is formed of earth and slag or water masses that are whirled upward.

The detonation cloud is formed from the fireball which gradually becomes colder due to enlargement and energy radiation. Depending on the type of detonation, it consists mostly of the condensed wreckage of the nuclear weapon, including the radioactive detonation products, atmospheric dust, and vaporized as well as unvaporized ground material or water. It is typical of this condensation cloud that it above all contains small and very small particles (aerosols). The quantity and type of soil material (water), which is swept upward by the suction effect hose that is formed due to the fast climbing speed of the fireball, depend on the detonation intensity, the detonation altitude or depth, and the nature of the detonation area. Here we are dealing primarily with large and larger particles which, after detonation, rapidly fall back into the detonation area and its immediate vicinity.

Because the radioactive detonation products in fact are to be found exclusively in the condensation cloud, the character of the terrain's radioactive

1.4.2.4. Multi-Phase Nuclear Weapons with Cobalt Jacket

In contrast to the function of the uranium jacket, which is used to release nuclear fission energy, the job of a cobalt jacket is not to increase the detonation energy but rather to produce additional large quantities of radioactivity. Although such constructions are very questionable from the military viewpoint, we might nevertheless present some viewpoints concerning such a weapon. Nuclear reactions as a result of which there is a powerful neutron flow can be used to trigger additional nuclear processes. Thus, it is possible, for example, if a nuclear weapon has an additional jacket of Co-59, to convert the latter into Co-60 through neutron capture. Co-60 is a beta-gamma-active radionuclide with a half-life of 5.3 years.

In a multi-phase nuclear weapon with a nuclear synthesis energy share of 10 Mt, about 1.5 t Co-60 can be produced in this fashion. This corresponds to an original radioactivity of $1.5 \cdot 10^9$ Curie or, by way of comparison, to the radioactivity of 1.5 million kg radium.

A high-altitude air burst of such a weapon would therefore lead to an extremely dangerous worldwide radioactive contamination of the atmosphere and the earth's surface which, because of the slow attenuation of radiation, would be connected with an enormous radiation exposure for large population segments. (See also the statements in Chapter 7, in this connection.)

1.4.3. Structure of Nuclear Synthesis Weapons

It follows from what we have said so far in Section 1.4.1. that minimum temperatures on the order of 10^6 °K are necessary to initiate thermonuclear reactions.

So long as one had to depend exclusively on nuclear fission fuses to generate these ignition temperatures in the synthesis charge, one could not speak of nuclear synthesis weapons, regardless of the ratio between the released detonation energies of the first and the second detonation phases.

A nuclear synthesis weapon within the meaning of the concept definition given in Section 1.1. thus exists only if it is possible to generate the necessary ignition temperatures in ways other than through nuclear fission fuses.

Some test detonations in years past and subsequent discussions in the literature indicate that such possibilities obviously exist not only in terms of theory but that they are already being used in practice to a certain degree. In looking at this kind of statement there is no question that the production of a "clean" nuclear synthesis weapon introduces a whole series of extremely complicated problems in physical-technical respects.

Kotchari[44] already pointed out that there is basically a possibility of using ordinary chemical explosives to initiate thermonuclear reactions. Reference was made here to the generation of the required ignition temperatures by means of successive hollow-charge explosions.[45]

Table 1.11. Comparison of Energy Concentrations from Detonations of Nuclear Fission Weapons and the Explosive TNT

	Nuclear weapon	TNT
Energy concentration, kcal cm^{-3}	10^7	1.5
Maximum temperature in reaction zone °K	$30 \cdot 10^6$	$5 \cdot 10^3$
Maximum pressure in reaction zone, atm abs	$20 \cdot 10^9$	$2 \cdot 10^5$

The maximum temperature in the reaction zone can approximately be estimated as follows:

$$T = \sqrt[4]{\frac{E_{Det}}{\theta \cdot F_{KL} \cdot t_1}} \qquad (1.19)$$

T--Thermodynamic temperature/°K
E_{Det}--Detonation energy/erg; see Formula 1.9
θ--Constant ($\theta = 5.7 \cdot 10^{-5}$ erg $cm^{-2}s^{-1}°K^{-4}$)
F_{KL}--Surface of nuclear charge/cm^2 ($F_{KL} \approx 30 \cdot q^{2/3}$)
t_1--Time/sec during which 90 percent of the detonation energy are released; see Table 1.8 or Formula 1.18.

The maximum pressure in the reaction zone can be estimated roughly as follows:

$$p = 9{,}87 \cdot 10^{-7} \cdot m \cdot k \cdot T \qquad (1.20)$$

p--Maximum pressure in reaction zone/atm abs
m--Number of particles per cm^3 gas/1[illegible]/cm^3
k--Boltzmann constant ($k = 1.38054 \cdot 10^{-16}$ erg $°K^{-1}$)
T--Thermodynamic temperature/°K

The formula given for the calculation of the maximum pressure in the reaction zone goes back to the kinetic gas theory according to which the gas pressure is roughly proportional to the number of particles per volume unit and the thermodynamic temperature.[37] For the computation we can assume roughly the following:

$$m \approx 4 \cdot 10^{24} cm^{-3}.$$

Review Questions

1.11. What fundamental connection is there between nuclear binding energy and mass effect?

Table 1.6. Brief Description of Nuclear Explosives

1	Nuklid	$^{233}_{92}U$	$^{235}_{92}U$	$^{239}_{94}Pu$
2	Kernmasse, absolute kg	$3{,}8494 \cdot 10^{-25}$	$3{,}9027 \cdot 10^{-25}$	$3{,}9693 \cdot 10^{-25}$
3	Kernmasse, relative ME	233,03784	235,04232	239,05053
4	kritische Masse kg[1])	7,5	22,8	5,6
5	Spaltneutronen je Kern	2,5	2,4	2,9
6	Dichte g cm^{-3}	18,7	19,0	19,6
7	T, Alphazerfall a	$1{,}6 \cdot 10^{5}$	$7{,}1 \cdot 10^{8}$	$2{,}4 \cdot 10^{4}$
8	T, spontane Spaltung a	$3{,}0 \cdot 10^{17}$	$1{,}8 \cdot 10^{17}$	$5{,}5 \cdot 10^{15}$
9	rel. Häufigkeit des Isotops bzw. Brutstoff	Th-232[2])	0,71 %	U-238[3])

Key: 1—Nuclide; 2—Nuclear mass, absolute; 3—Nuclear mass, relative; 4—Critical mass; 5—Fission neutrons per nucleus; 6—Density; 7—T, alpha decay; 8—T, spontaneous fission; 9—Relative frequency of isotope or breeder substance.

(1) The data pertain to a system made up of metallic U-233, U-235, or Pu-239 with a standard water reflector. For nuclear fission weapons, the values are considerably lower.

(2) The production of U-233 takes place in breeder reactors from Th-232 according to the following scheme:

$$^{232}_{90}Th\,(n,\gamma)\,^{233}_{90}Th \xrightarrow{\beta^-} {}^{233}_{91}Pa \xrightarrow{\beta^-} {}^{233}_{92}U$$

(3) The production of Th-239 from U-238 is based on the following scheme:

$$^{238}_{92}U\,(n,\gamma)\,^{239}_{92}U \xrightarrow{\beta^-} {}^{239}_{93}Np \xrightarrow{\beta^-} {}^{239}_{94}Pu$$

The detonation energy of 1 kg TNT corresponds roughly to an energy amount of 1,000 kcal. If we therefore insert q in terms of kt in the following expression for the detonation equivalent of a nuclear fission weapon, then we get the following for the total energy released as a function of the detonation intensity:

$$E_{ges} = 10^6 \cdot q \quad \text{kcal} \qquad (1.8)$$

Table 1.2. Data on the First A and H Bomb Test Detonations"[26]

Staat	»A-Bombe« 2	Ort	3	Bemerkungen	»H-Bombe« 2	Ort	3	Bemerkungen
USA	16.07.1945	Alamogordo (New Mexiko)	4	»Trinity-Test« Pu-239, 10 kt Implosionsprinzip	01.11.1952	Elugelab (Stiller Ozean)	6	Test »Mike« D,T; 5 Mt
			5	Stahlturm (30 m)	28.02.1954	Bikini (Stiller Ozean)	7	nicht transportabel LiD; 15 Mt
							8	transportabel
9 UdSSR	29.08.1949		10	kt-Bereich Pu-239	12.08.1953		11	Mt-Bereich LiD
							8	transportabel
England	03.10.1952	Monte Bello (Australien)	12 10	kt-Bereich	15.05.1957	13 Christmas-Insel (Stiller Ozean)	6	11 Mt-Bereich
14 Frankreich	13.02.1960	Reggane	15	60 ... 70 kt	24.08.1968	Fangataufa (Stiller Ozean)	6	2 Mt
			16	Turm (100 m)				
17 VR China	16.10.1964	18 Provinz Sinkiang	16	U-235, 20 kt Turm	17.06.1967	18 Provinz Sinkiang		3 Mt

Key: 1—Country; 2—Place; 3—Remarks; 4—Implosion principle; 5—Steel tower; 6—Pacific Ocean; 7—Not transportable; 8—Transportable; 9—USSR; 10—Kt range; 11—Mt range; 12—Australia; 13—Christmas Island; 14—France; 15—Sahara Desert; 16—Tower; 17—PRC; 18—Province of Sinkiang.

Timely and steady supply of units with protective equipment;

Rapid elimination of the consequences of enemy nuclear strikes.

1. Classification, History, and Structure of Nuclear Weapons

1.1. Principles of Subdivision and Fundamental Concept Definitions

Nuclear weapons are mass annihilation weapons. At this time there are three major groups of mass annihilation weapons: Nuclear weapons, chemical weapons (CW agents), and biological weapons (BW agents).[2]

The essence of mass annihilation weapons consists in the fact that their injuring or destructive effects always extend to a more or less large and continuous surface area, that, compared to the means of application, tremendous effects are produced, and that the effects of their employment as a rule cannot be confined only to the militarily necessary degree.

Each group of mass annihilation weapons has specific combat properties and annihilation effects. This is why the determination of a clear sequence is hardly possible. Nevertheless, nuclear weapons hold primacy inasmuch as they are not directed practically exclusively against human beings, such as chemical and biological weapons, but rather produce heavy destruction of combat equipment, buildings, installations, etc.

The general concept of "nuclear weapons" encompasses all types of weapons whose annihilating and destructive effects are based on the release of nuclear energy.

It is basically possible, first of all, through certain unguided nuclear reactions to release nuclear energy in the form of a detonation and, besides, to utilize the nuclear radiation, which is released as a result of the decay of natural or artificial radionuclides, as the sole annihilation factor.

Detonating nuclear weapons are weapons in which the release of energy is based on the foundation of nuclear fission and/or nuclear synthesis reactions in the form of detonations. Radioactive warfare agents are radionuclides which have been assembled especially for wartime use; they can be employed in various aggregate states and with different means and methods.

In the following we will use the term nuclear weapon always in the sense of "detonating nuclear weapon" while on the other hand we will be speaking of radioactive warfare agents.

Nuclear weapons can be arranged according to a series of viewpoints:

According to the type of energy released;

According to the detonation intensity (the detonation equivalent);

According to the type of nuclear charge employed;